Can India's Future Needs of Electricity be met by Renewable Energy Sources ?

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1. Introduction

- Today India's needs for electricity are supplied by
  - Fossil fuels
  - Nuclear energy
  - Renewable energy sources
- In the future (about 100 or more years from today), our supplies of fossil fuels will be essentially exhausted, and we will have to rely either on nuclear energy or on renewable energy sources or both.

- **Question : Can renewable energy sources alone meet our future needs of electricity?**

- **Why do we pose this question ? Renewable sources would last indefinitely. For this reason, they need to be developed to the fullest extent to ensure sustainable development .**

- **India's long term energy policies depend on the results such studies.**

The Present Scenario

Installed capacity on 31-12-2013 = 236,174 MW

Electricity produced in 2013-14 = 900 to 1000 TWh

Contribution : Fossil fuels 80%, renewable energy sources 17%, nuclear energy 3%

Per capita production = 800 to 900 kWh/year

2. Estimating India's Future Needs for Electricity

- Annual per capita needs of electricity
- Total need for electricity in the future

Annual per capita needs of electricity

Extensive studies by Amulya Reddy et al.

The focus is on electrical energy inputs needed for activities grouped under broad headings like residential, commercial, transportation, manufacturing, agriculture, mining and construction, etc

Main finding : Average per capita requirement of electricity (ACE) = 1840 kWh/year

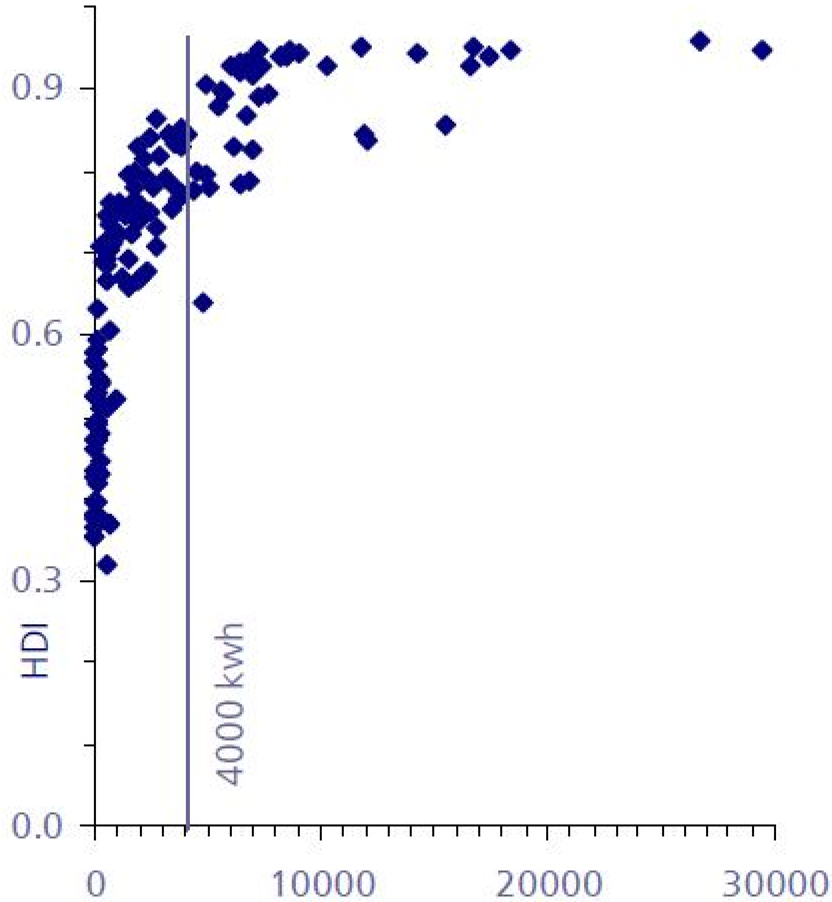
Human Development Index (HDI)

HDI is a measure of human well-being.

Good correlation between HDI and annual per capita production of electricity (ACE).

ACE(kWh/yr)	0	800	2000	4000	Over 4000
HDI	0.3	0.6	0.8	0.9	0.9 to 0.92

Desirable to have a value of 4000 kWh/yr



HDI= Human development index. Source: UNDP (2007)

Plot of HDI vs. MACE for the countries of the world

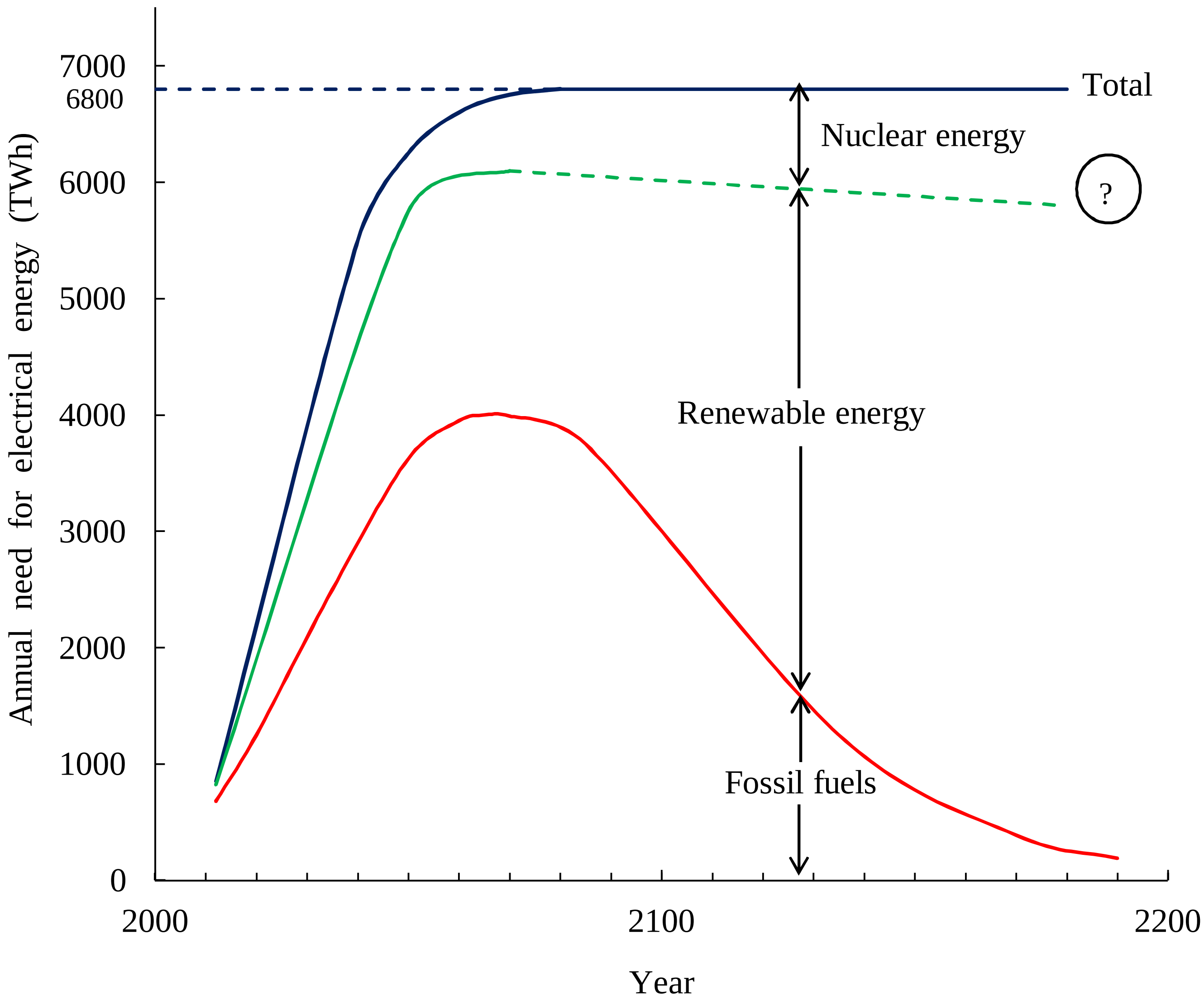
What value should India aim for in the long run?

- Keeping in mind the need for frugality, it may be best for India to aim for the value of 1840 kWh/yr calculated by Reddy et al. This would be adequate for providing a good standard of living.
- However, it is also argued that we should aim for a value of 4000 kWh/yr so that the HDI is 0.9

The population of India is expected to stabilize around 1700 million in the period 2071-81

Total Need for Electricity in the Future

Per capita need (kWh/yr)	Population (million)	Total need from about 2070 onwards (TWh/yr)
1840	1700	3128
4000	1700	6800



Variation of India's Total Need for Electricity over the Years if Individual Need is Assumed to be 4000 kWh/year. Possible Contributions of Fossil Fuels, Renewable Energy and Nuclear Energy are also Indicated.

3. A Case Study of Two Countries

	Germany	France
Annual per capita production (kWh/yr)	7209	8140
Human development index	0.92	0.89

The two countries are following different policies for producing electricity

Germany

Year	Generation (TWh)	Percent contribution		
		Fossil fuels	Nuclear	Renewables
2000	542	62.7	29.7	7.6
2009	554	58.9	23.1	17.9
2011	577	60.2	17.8	22.1

Germany has adopted a policy which requires it to switch over from nuclear energy and fossil fuels to renewable energy in about four decades.

France

Year	Generation (TWh)	Percent contribution		
		Fossil fuels	Nuclear	Renewables
1980	251	47.0	25.3	27.6
2000	512	9.1	77.1	13.8
2009	507	9.2	76.8	14.1
2011	532	8.5	79.0	12.5

As early as 1974, France adopted an energy policy of expanding its nuclear energy program so that it would eventually provide most of its electricity.

4. Potential of Renewable Energy Sources for Generating Electricity

Main contributors

- Solar power – Photovoltaic conversion
  - Thermal energy
- Hydroelectric power
- Wind energy
- Power from biomass

Estimating the capacity of an energy source to generate electricity

Estimation done by considering

- data on solar radiation, wind speeds, water flows, efficiencies of devices, etc.
- requirements of space
- degree of commercialization thus far and the rate at which it has occurred
- cost effectiveness.

Solar Energy – Photovoltaic and Thermal

Installed capacity : PV - 2647 MW (31-12- 2013)
Thermal – 50 MW

Many plants under erection. Ambitious plans to install 20,000 MW by 2022.

Major issues
(i) Initial cost – About Rs 15 crores per MW
(ii) Need 2 hectares of open land per MW

Limitation - Energy available for only 7 or 8 hours a day.

How much energy can we expect to generate from solar energy (PV and thermal) ?

Barren and uncultivated land = 200,000 sq km

Assume 5% of this land is acquired.

At 2 hectares per MW, installed

capacity = 500,000 MW

Annual plant load factor (APLF) = 0.18

Annual electricity production = 788.4 TWh

Electricity produced by solar PV and thermal routes as a function of land acquired

Percent of land acquired	5	10	20
Annual production of electricity (TWh)	788.4	1576.8	3153.6

5 MW Solar PV plant, Pulivendula,Andhra Pradesh

1 MW Solar Thermal Power Plant – IIT Bombay
Part of Solar Collector Array

Small Capacity Roof-top Solar PV Systems

Capacity of a typical roof-top system = 3 kW

Electricity generated = 4.5 MWh/year

How many such systems can we expect to install ?

In 2070, India will have 425 million households, half in urban areas and half in rural areas.

Difficult to install roof-top systems in urban areas.

In rural areas, it may be possible at most to install systems in about 10% (i.e. 20 million) households

Electricity produced by solar roof-top PV systems

Number of households (million)	5	10	20
Annual production of electricity (TWh)	22.5	45	90

Hydroelectric Power

- Large units (> 25 MW)
- Total reserves = 148,700 MW
- Present installed capacity : About 25%
- Average APLF = 0.37

- Electricity production

Percent of reserves exploited	40	60	80
Annual production of electricity (TWh)	193	289	386

Hydroelectric Power (contd.)

- Small units (< 25 MW)
- Total capacity available = 15,384 MW
- Present installed capacity : About 25 %
- Use same APLF as for large units.

- Electricity production

Percent of reserves exploited	40	60	80
Annual production of electricity (TWh)	20	30	40

Wind Energy - on land

- Growth in capacity over the last 20 years has been spectacular.

- Installed capacity on 31-12-2013 = 21,136 MW

- Limitation : Available for only 4 or 5 hours a day.

- Latest findings indicate that the wind potential in India is much more than the value of 65 GW or so accepted earlier.

Wind Energy - on land (contd.)

Latest findings

- Hossain, Sinha and Kishore (2011) - HSK
- Phadke, Bhavirkar, Khangura (2012) – PBK

	Generation potential (GW)	Hub height (m)	APLF
HSK	2075	80	> 0.2
PBK	2006	80	> 0.2

Electricity produced by wind energy on land

Percent of potential exploited	20	40	60
Annual production of electricity (TWh)	703	1406	2108

Note : Potential = 2006 GW, hub height = 80 m

APLF = 0.2

Wind Energy - off shore

- Considerable scope for exploiting this resource.
- Present installed capacity in India : Nil
- Wind mapping is in progress off shore.

Wind Energy – off shore (contd.)

Potential for India estimated to be 1100 TWh/year.

(Lu, McElroy & Kiviluoma, Proc. National Academy of Sciences of USA, 2009)

Percent of potential exploited	20	40	60
Annual production of electricity (TWh)	220	440	660

A Typical Wind Farm

Power from Biomass

- Plant life – trees, plants, bushes, grasses, algae, etc. – and residues
- Much of India's non-commercial energy required in the form of heat is obtained from biomass.
- Thus there are limitations to the availability of biomass which can be used for electricity production.

Power from Biomass (contd.)

- Generally, biomass residues like rice husk, straw, coconut shells, saw dust, bagasse, molasses are used.

- Installed capacity on 31-12-2013 : 4000 MW
- Potential capacity (MNRE) : 23,000 MW
- Availability of biomass is seasonal. APLF = 0.3

- Annual production of electricity if potential is fully exploited = 60 TWh

Total Capacity of Renewable Energy Sources for Generating Electricity

Estimated annual electricity production (TWh/yr)

	Min	Max
Solar power (PV + thermal) (including decentralized systems)	810.9	3243.6
Hydroelectric power	213	426
Wind energy (on land & off shore)	923	2768
Biomass + others	77	77
TOTAL	2023.9	6514.6

S P Sukhatme, Current Science, 2012, 103, 1153-1161

Comment :

- **On an annual basis, the estimated maximum production of 6514.6 TWh from renewable energy sources is reasonably close to the need of 6800 TWh.**

Question :

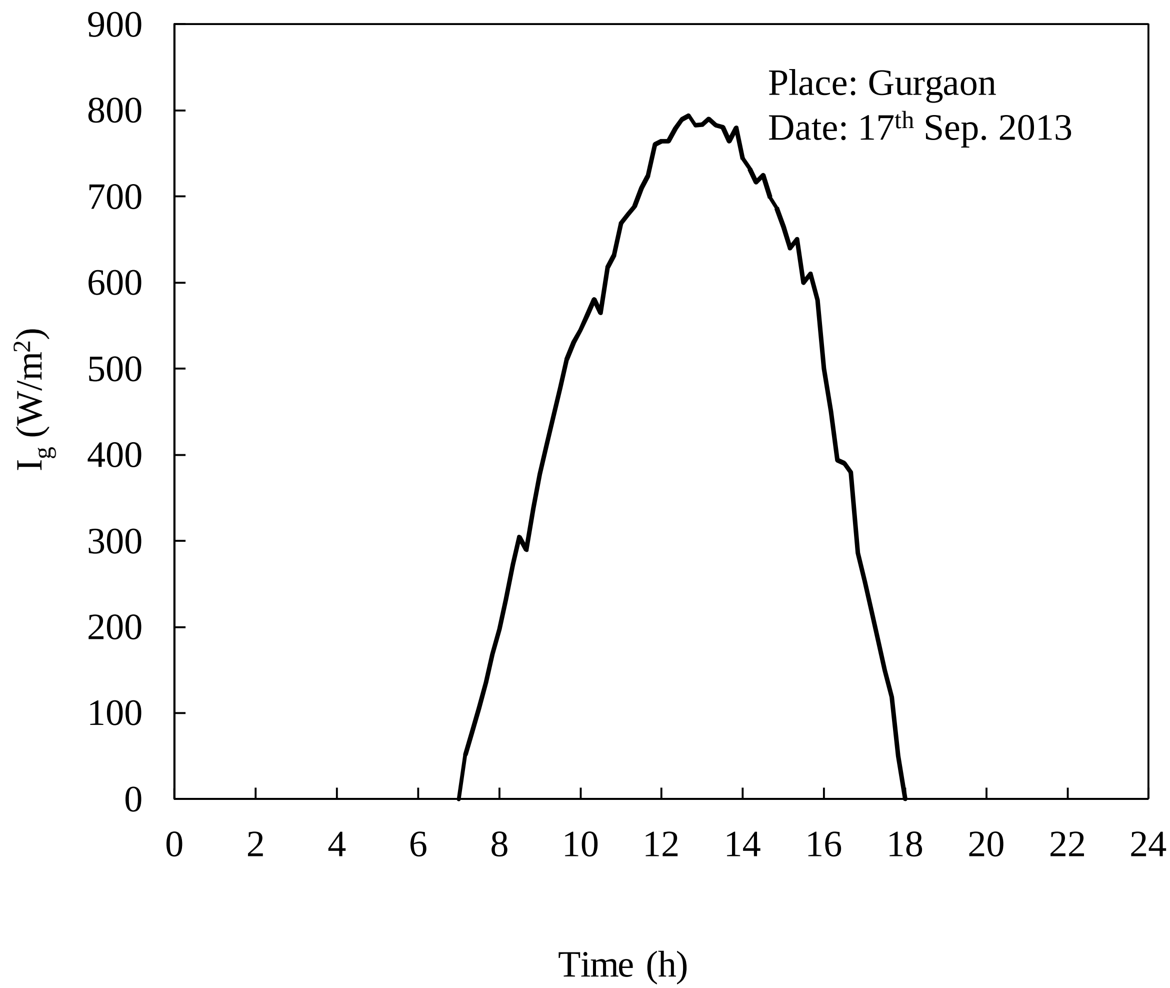
- **Is this matching on an annual basis enough ?**

5. Technical Challenges in Using Renewable Energy Sources

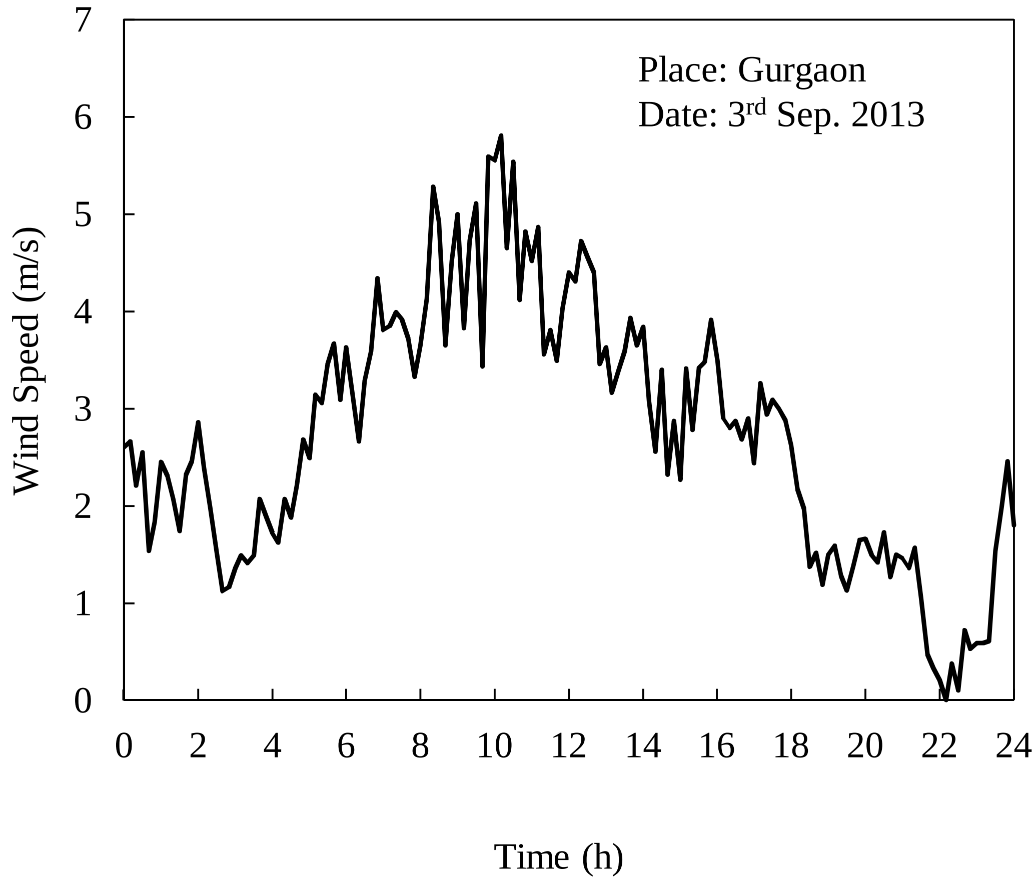
It is not enough to match demand with supply on an annual basis alone. Renewable sources must be able to meet the need for electricity continuously round the clock for all days of the year.

1. **Smart Grids**

   Renewable sources like solar and wind energy are intermittent sources with fluctuating outputs.



Typical Variation of Global Radiation on a Clear, Sunny Day



Typical Variation of Wind Speed over a Day

Technical Challenges (contd.)

- If solar and wind energy are to supply the bulk of our electrical energy in the future, power grids will have to become smart grids.

- Smart grids use information and communication technology to gather and act on information about the behavior of the supply and demand side in an automated fashion. Such grids help to improve efficiency, reliability and economics.

Technical Challenges (contd.)

Thus, ‘smart’ power grids should have the capability to

- Coordinate and control the supply of thousands of relatively small distributed and fluctuating solar and wind power sources.
- Take that supply with the help of an extensive and robust transmission grid from where it is produced to where it is consumed.
- Control and manage power consumption of thousands of consumers on the demand side.

Technical Challenges (contd.)

2. <u>Energy Storage Systems</u>

Develop energy storage systems for short-term and long-term storage

(a) To even out the mismatch in diurnal variation.

(b) To store energy on days when supply exceeds demand and to provide energy to match demand during days when there are lulls in wind speed or periods of cloudy weather.

Technical Challenges (contd.)

- **Short-term energy storage systems**

  - Pumped storage systems

  - Electric battery storage

  - Compressed air storage

- **Long-term energy storage**

  - Would probably be chemical storage, hydrogen or methane.

Technical Challenges (contd.)

3. Over-sizing the Power Capacity

Recent simulation studies have shown that one can match the demand by over-sizing the electrical capacity. Over-sizing by a factor of three is recommended to achieve reliability greater than 99.9 %.

Even if the technical challenges can be resolved, is the economics affordable ?

6. Concluding Remarks

Acknowledgements

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